DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150693

PROTOTYPE SOLAR HEATING AND COMBINED HEATING AND COOLING SYSTEMS (QUARTERLY REPORT NO. 5)

Prepared by

General Electric Company - Space Division
Post Office Box 8661
Philadelphia, Pennsylvania 19101

Under Contract NAS8-32092 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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This work was accomplished under the technical management of Mr. William L. Moore, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

The General Electric Company is developing eight prototype solar heating and combined heating and cooling systems. This effort includes development, manufacture, test, installation, maintenance, problem resolution, and performance evaluation.

All cost data have been removed from this report.

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INTRODUCTION

The Quarterly Status Report (Data Requirements Item No. 500-10) provides a summary of the cost, schedule and technical progress of the program. Since it includes and extends the information included in the Monthly Status Reports (Data Requirements Item No. 500-11) it also meets the contract requirement of a monthly status report. It is supplemented by the financial status report (Data Requirements Item No. 500-27) submitted under separate cover.

The report format is:

- Part I - Summary
- Part II - Cost
- Part III - Schedules
- Part IV - Technical Performance

The report is integrated with the program management systems being used on the program, so, where possible, multiple use of program data such as schedules or financial status reports has been accomplished.

PART I

SUMMARY

1.1 COST

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1.2 SCHEDULE

The working program schedule is posted on the walls of the Program Control Room and is used to monitor program status at daily "standup" meetings. Reviews with GE management are held in the Control Room to take advantage of the detail schedule data base. A summary schedule is shown in Figure 1-1.

Definition of the Operational Test Sites is a continuing schedule problem. Prototype design reviews have been rescheduled and rescoped to adapt to the number and dates of the identified sites. A mini-design review was held for the two commercial heating Operational Test Sites.

Testing was an important factor this period. The important collector performance verification test was initiated but performance problems occurred which

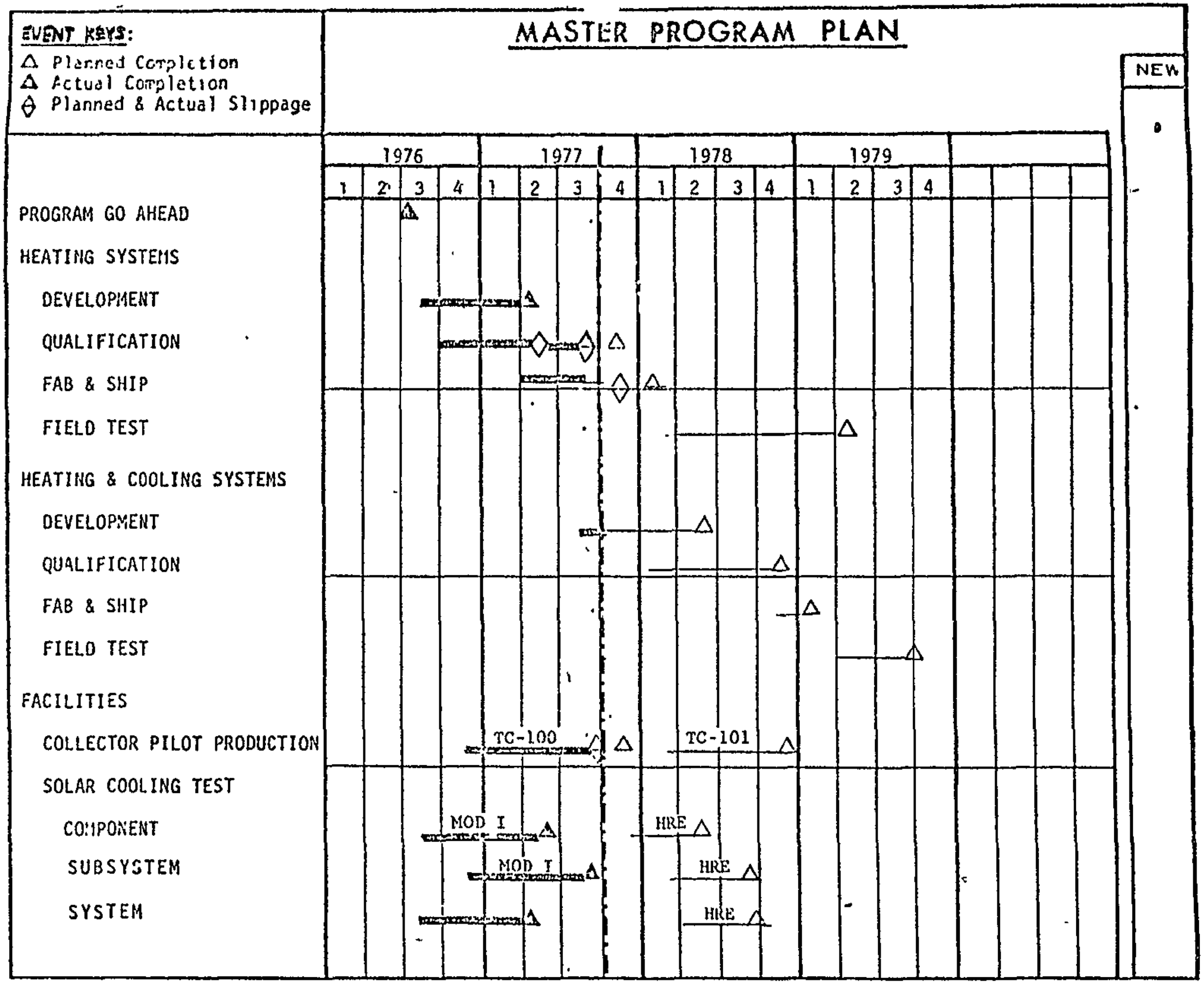

Figure 1-1. Master Program Plan

make a retest mandatory. The horizontal TES tank design was verified by test. The solar integrator vendor ran into problems in qualification testing and some redesign of this component will be required.

Hardware delivery of the collector shrouds is a schedule limiting item for the test site hardware. Because of technical problems, production has not started.

1.3 TECHNICAL PERFORMANCE

1.3 1 PROGRAM MANAGEMENT

Program direction continued per plan. Highlights of the period were the program redirection meetings with NASA and ERDA, the submission of the redirection change proposal, and the prototype design review for the commercial heating sites.

1.3.2 DEVELOPMENT

System analysis activity this period was directed toward prediction of the performance of the prototype systems and trade studies for the design of the modified cooling subsystem. Analytical models of the TC-101 solar collector were generated and used to predict the performance of configuration candidates A significant result of the analysis was an improved understanding of the importance of EER in system performance and economics.

The solar collector verification tests were initiated and a performance problem was discovered. This is attributed to the selective coating and a task force is investigating the reasons for the problem prior to initiating production of TC-100 shrouds.

Designs were completed for the two commercial heating prototype systems (Milwaukee and Spokane) Hardware lists were prepared A revised list of sensors for the Normal site was generated at an integration meeting with IBM.

Preliminary studies indicate the impact of the higher temperatures and pressures in the redirected solar cooling system on the design of ancillary components will be small.

A major activity in this task was the preliminary design of the redirected cooling subsystem, designated HRE. Fluid performance studies were carried out with the recommended fluids being FC-188 in the Rankine engine and R-114 in the heat pump subsystem. Configuration and performance studies resulted in the recommended configuration of a unitary expander - rotary compressor - motor unit. The system will utilize two compatible fluids with a shaft seal between them to avoid the penalties associated with a single fluid system. Preliminary designs were prepared for the system elements including the controls.

1.3.3 DELIVERABLES

Hardware procurement for the Normal OTS proceeded during this period. Items are being accumulated for the First Article Review which is scheduled early in the next reporting period. Items not on hand at the end of this period included the solar collector shrouds, solar integrator, energy management module, and a few smaller hardware items.

Approval to order equipment for the Milwaukee and Spokane test sites was received at the Prototype Design Review and the ordering process has been initiated. Long lead items such as the TES tank were ordered, with NASA approval, prior to the PDR.

1.3.4 OPERATIONAL TEST SITE

OTS activity focused on the Normal, Milwaukee, and Spokane sites. A&E activity was initiated. A bid package was issued to candidates for installing the Normal, Illinois system.

The late identification of sites has resulted in a revised schedule for the prototype delivery and installation.

1.4 VARIANCES

Requested variance data is summarized in Table 1-2.

PART II

COST

This section has been deleted

PART III

SCHEDULES

Summary program schedules are shown in Figures 3-1, 3-2, and 3-3. These schedule data are extracted from the detailed program working schedules posted in the Control Room at Valley Forge.

Figure 3-1 is the summary key events schedule. Significant scheduled customer events included a prototype design review for heating systems HCOMM 1 - Milwaukee and HCOMM 2 - Spokane.

Key activities in the solar array area were the completion of the shroud breakage failure investigation and the initiation of a coating problem investigation as a result of low performance during verification testing.

Redirection of the solar cooling portion of the program resulted in a reschedule for the cooling development activities. The delivery date was delayed to provide time for the development of equipment to meet the redirected design requirements. The three ton unit in the originally proposed configuration was assembled and is being checked out. Expander performance tests continued.

Equipment for the first residential heating system was ordered and many items received. Solar integrators were received from ZIA and a unit placed on the outdoor test stand. The horizontal configuration TES tank was received and tested to assure satisfactory performance. Installation plans are being prepared.

Design of the heating systems for two commercial operational test sites was completed and the Prototype Design Review was held. Long lead items were ordered and following the PDR the ordering process was started for the remaining equipment.

Figure 3-2 is the schedule for the WBS elements. The activity associated with the heating and cooling systems has been rescheduled.

Figure 3-3 shows the data deliveries. During this period all scheduled software deliveries were completed except the new Technology Report which is in preparation.

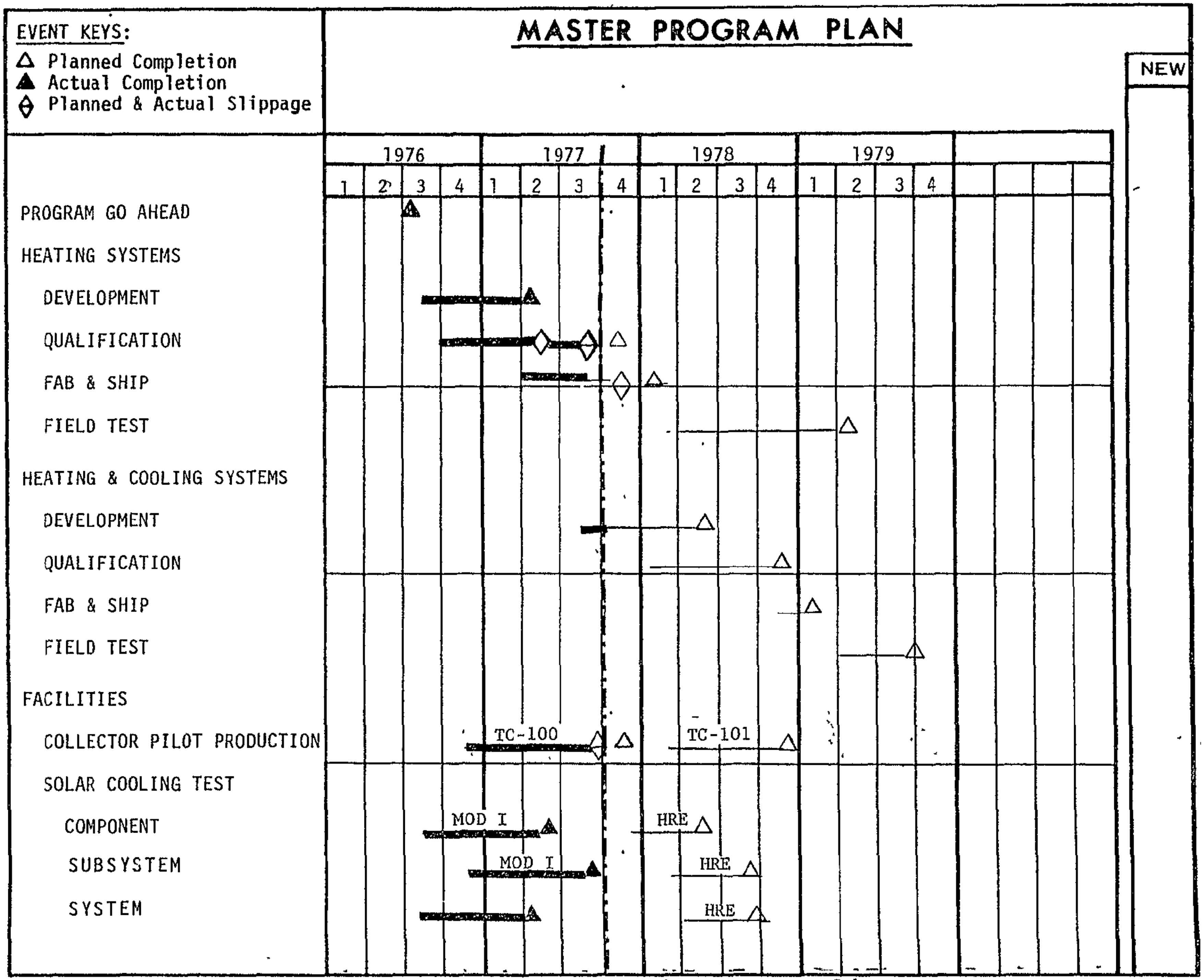

Figure 3-1. Master Program Plan

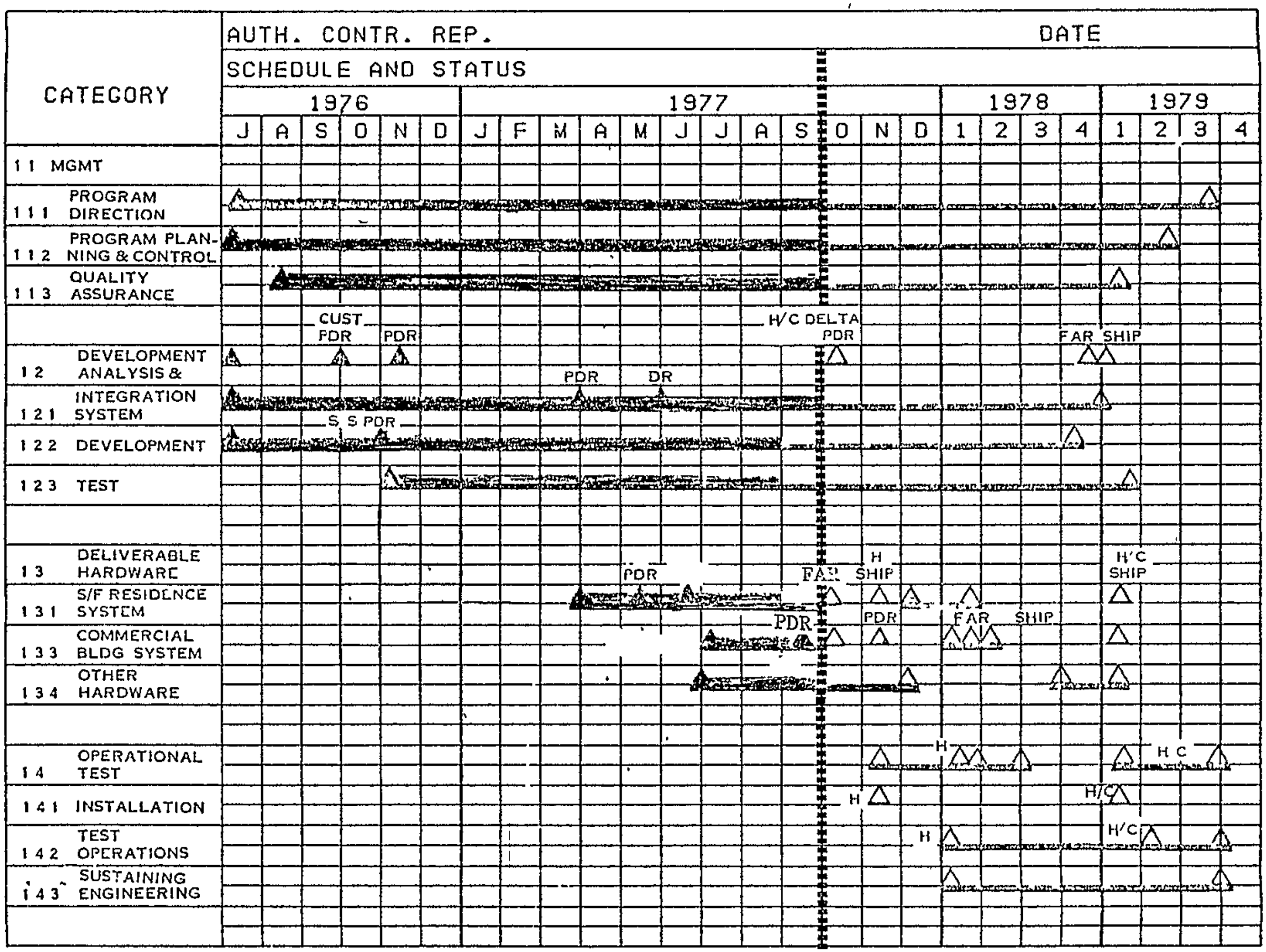

Figure 3-2. WBS Element Schedule and Status

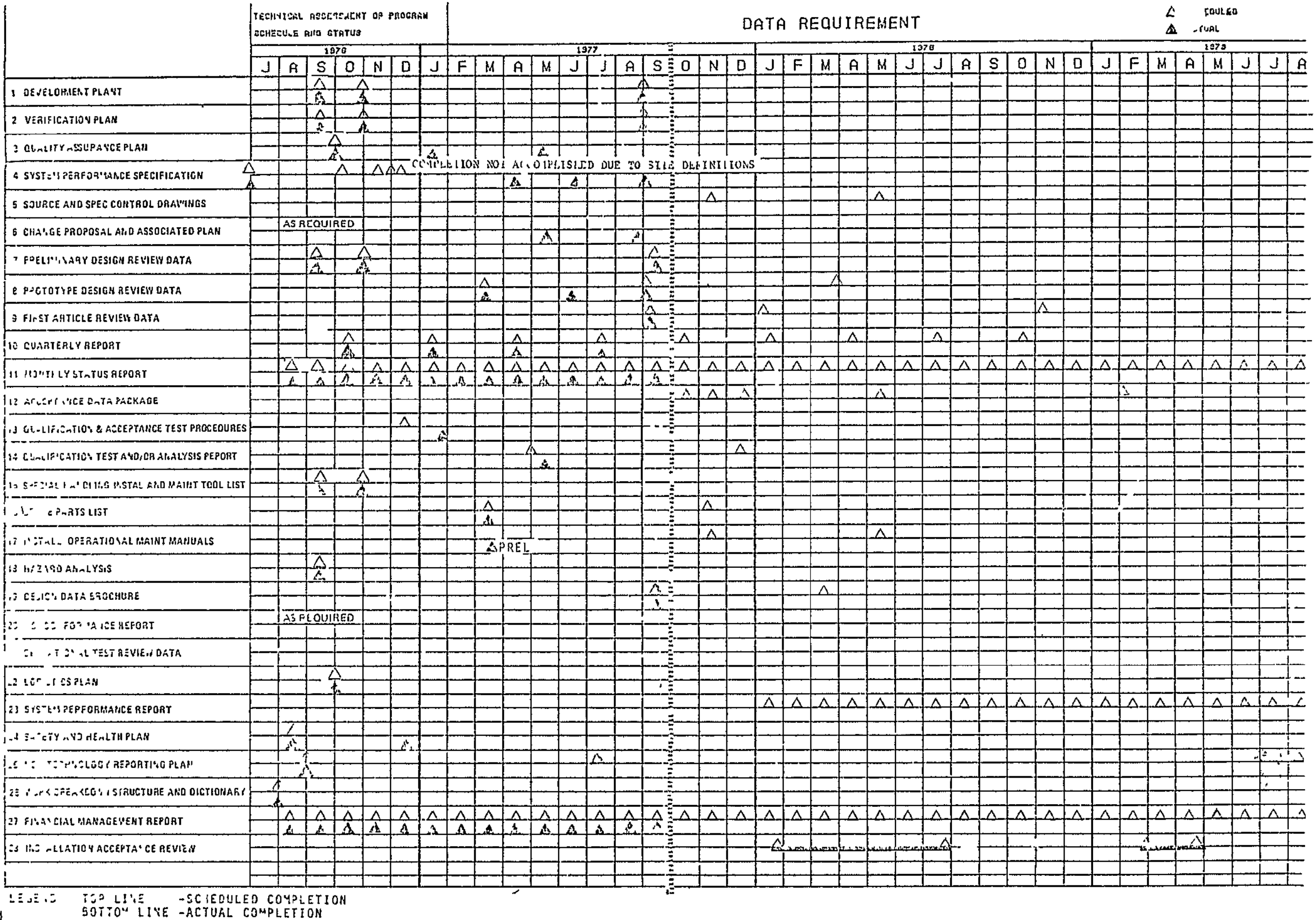

Figure 3-3. Data Requirements Status

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SECTION 1

TASK 1.1 - MANAGEMENT

1.1 PROGRAM DIRECTION (WBS 1.1.1)

During this period program operation continued in the manner established during the initial quarters. The program team, shown in Figure 1.1-1, is the same as shown in the last quarterly report except for the following changes:

1. J. Hatman replaces E. Ernst in the Product Development Engineering assignment. Mr. Ernst had been acting in this role and has assigned the responsibility to Mr. Hatman.

2. T. Duff has been added to fill the System Project Engineer assignment

As a followup to the program redirection meetings discussed in the previous report, a revised program was discussed at MSFC on 7/12/77. It was refined and discussed with MSFC personnel at Valley Forge on 7/26/77 and presented to ERDA at ERDA Headquarters on 7/27/77. The revised program was defined in a Request for Change Proposal from MSFC in August and a Change Proposal for the redirected program submitted at the end of August. The Change Proposal included revisions to the Development Plan and the Verification Plan. The original versions of these documents were disapproved several months after their submittal because their content no longer matched the program (after redirection). In the interim period they had been used as program guidelines. Per NASA direction a short program summary was submitted on 9/12/77 for use in explaining the program to the public. A meeting with NASA-MSFC and IBM was attended in Huntsville on 9/27/77 on the subject of instrumentation with emphasis on the sensor list for the Normal, Illinois, Operational Test Site.

During this period three candidate sites for single family residential heating and cooling operational test sites were visited in the Dallas/Fort worth area. Of the sites visited, the site at Southern Methodist University was considered the most

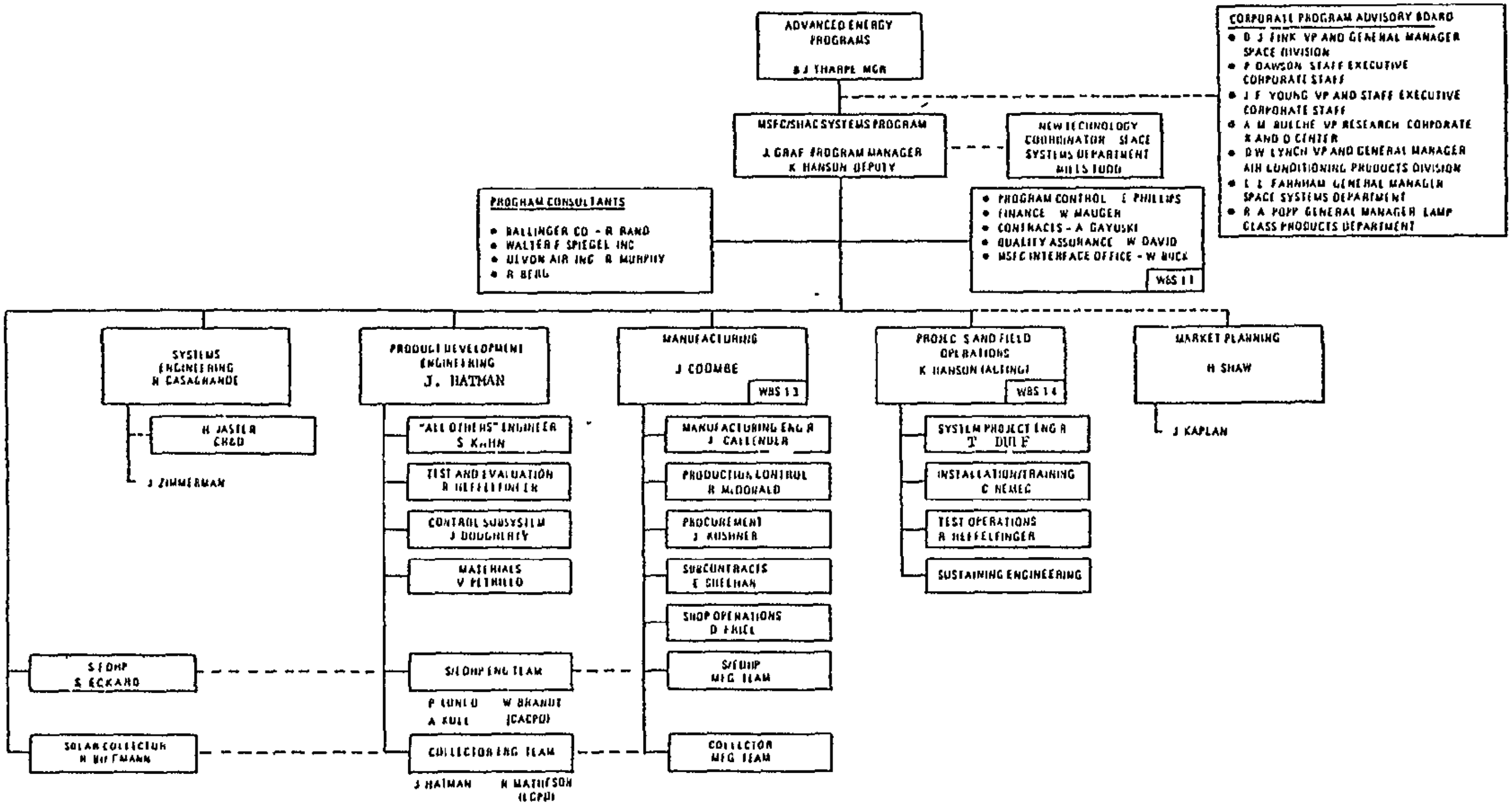

Figure 1.1-1. Program Organization

suitable. However, the redirection of the program in progress at that time precluded a firm recommendation of a site. Subsequently, this site was forwarded to ERDA as a selected site. The General Electric assessment of this site is not complete and its acceptance remains tentative at this time.

1.2 PROGRAM PLANNING & CONTROL (WBS 1.1.2)

1.2.1 PROGRAM CONTROL

The basic program control tool being used on this program is the control room. It was used during this period to schedule key milestones and program activities and monitor their status. This control room represents the official program schedule against which GE's technical status and progress is monitored. The scheduled data required for the monthly, quarterly and management reports is extracted from the control room posting. The schedules in the control room include an overall program summary with detailed task schedules on the side walls. The individual task sections of the control room schedules are monitored and maintained by the responsible task leaders. Daily program status meetings are held to follow hardware items. Problems involving interactions are identified and resolved at these meetings by the assignment of action items which are posted and monitored in the control room.

In the budgets area, the program was monitored on the basis of the profile presented in the first quarterly report. Overall budget results are posted in the control room and are available on a continuing basis for inspection by management.

1.2.2 DATA MANAGEMENT

The scheduled data submittals completed during this period were as follows:

Data Requirements No.	
- 1	Development Plan Revision 1
- 2	Verification Plan Revision 2
- 7	△ Preliminary H/C (redirected program) Design Review Package
- 8	Prototype Design Review Data Package (HCOM-1 and HCOM-2)

Data Requirements No.

- 9	First Article Review Data Package (HSF-2)
-10	Quarterly Report No. 4
-11	Monthly Status Reports (2)
-19	Design Data Brochure (Application Guide) Prel.
-26	Financial Management Report (2) (Monthly)
-27	Quarterly Financial Report

As of this date, 15 RIDs and 11 Action Items are still outstanding from the PDR's.

1.2.3 CHANGE CONTROL

The status of Change Proposals is as follows:

CP001 - Approved with exception of 001-6

CP002 - Cancelled

CP003 - Ft. Meade Site Design - Submitted 5/12/76

CP004 - Multi-Family Deletion - Response to RCP-301-77-010 - Withdrawn (See CP007)

CP005 - Response to TD-001 - Instrumentation Plan - Withdrawn

CP006 - Normal, Illinois Site Design and Installation - Submitted and Approved

CP007 - Revision to Collector and Cooling S/S - Response to RCP-301-77-011
Submitted 9/31/77

CP008 - Milwaukee Design & Installation - Part I in Process

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1.3 QUALITY ASSURANCE (WBS 1.1.3)

With the increasing build-up of production facilities and output of TC-100 collector parts and assemblies, there has been considerable interfacing with Air Force Quality Assurance. In addition to monitoring our inspection activity, they witnessed qualification testing of the prototype Solar Integrator, hail testing of the TC-100 collector, and heating system testing of the horizontal TES tank for Normal, Illinois.

Significant Quality Assurance Activities

1. The failure analysis report on breakage of TC-100 glass shrouds was issued with scratches induced during shroud installation on fin assembly as the most significantly contributing factor.
2. Quality Assurance, Collector Engineering, and Materials Engineering have developed a scratch resistant coating which doubles the safety margin over uncoated glass shrouds.
3. FAR activities were conducted for the acceptance of a Single Family Heating System to be installed at Normal, Illinois.

SECTION 2

TASK 1.2 - SYSTEM DEVELOPMENT

2.1 INTRODUCTION

The major program development activity this period was the analysis and preliminary design activity for the cooling subsystem which resulted from the program redirection. Other activities included the setup and test of a horizontal TES tank configuration and collector shroud evaluation. Preliminary design work was accomplished for the other portions of the solar heating and cooling system which resulted from the program redirection, including the definition of the TC-101 solar collector.

2.2 ANALYSIS AND INTEGRATION (WBS 1.2.1)

2.2.1 BASELINE SYSTEM CONFIGURATION

The system configuration of the heating only and heating and cooling baseline systems has not been modified. Incorporation of the higher temperature HRE requirements will only increase the operational temperature which will only change the rating of some components and not the configuration.

2.2.2 SYSTEM TRADE STUDIES

Several system trade studies were performed during this quarter and were reported in the Heating and Cooling Preliminary Design Data Package dated September 20, 1977. Studies conducted included performance characterization of the TC-101 series collector, heat pump operational characteristics as a function of ambient cut-off temperature and the economics of a solar heating and cooling system.

2.2.2.1 Collector Configuration

The higher temperature requirements of the HRE dictated usage of a cusp shaped collector which has been designated the TC-101 series. With the constraint that the TC-100 frame be utilized, system simulations were made to determine number of

shrouds per panel which will provide the energy at the lowest cost.

The 8 shroud system is being recommended because a 7 shroud system will require that the shroud coating be modified to withstand stagnation conditions.

2.2.2.2 Heat Pump Ambient Temperature Response

The operational characteristics of the heat pump and the solar system were examined to define the effect of different heat pump cut-off temperatures on total system performance. The heat pump was modeled such that only resistance energy would be utilized to satisfy the space energy requirements whenever the ambient temperature was below the set point value. Results of annual solar simulations, summarized in Figure 2.2-2, show that the increasing of the temperature at which only I^2R heat is utilized will not significantly increase the total energy required by the system.

2.2.2.3 Energy Savings and Economics of a Solar Heating and Cooling System

The energy and cost savings of a solar heating and cooling system is the differential in energy and cost of a solar and conventional system. System analysis using the thermal COP of the Rankine cycle, the EER of the conventional and solar systems and the seasonal and daily billing were performed to determine the value of the energy saved (ECE). The value is expressed as the levelized system price divided by levelized system savings. Figure 2.2-3 shows the representative energy savings for a single family residence located in Fort Worth, Texas and Figure 2.2-4 shows the ECE of this house as a function of the system COP and EER.

The effect of the rate structure (Figure 2.2-5) will produce significant reductions in the ECE.

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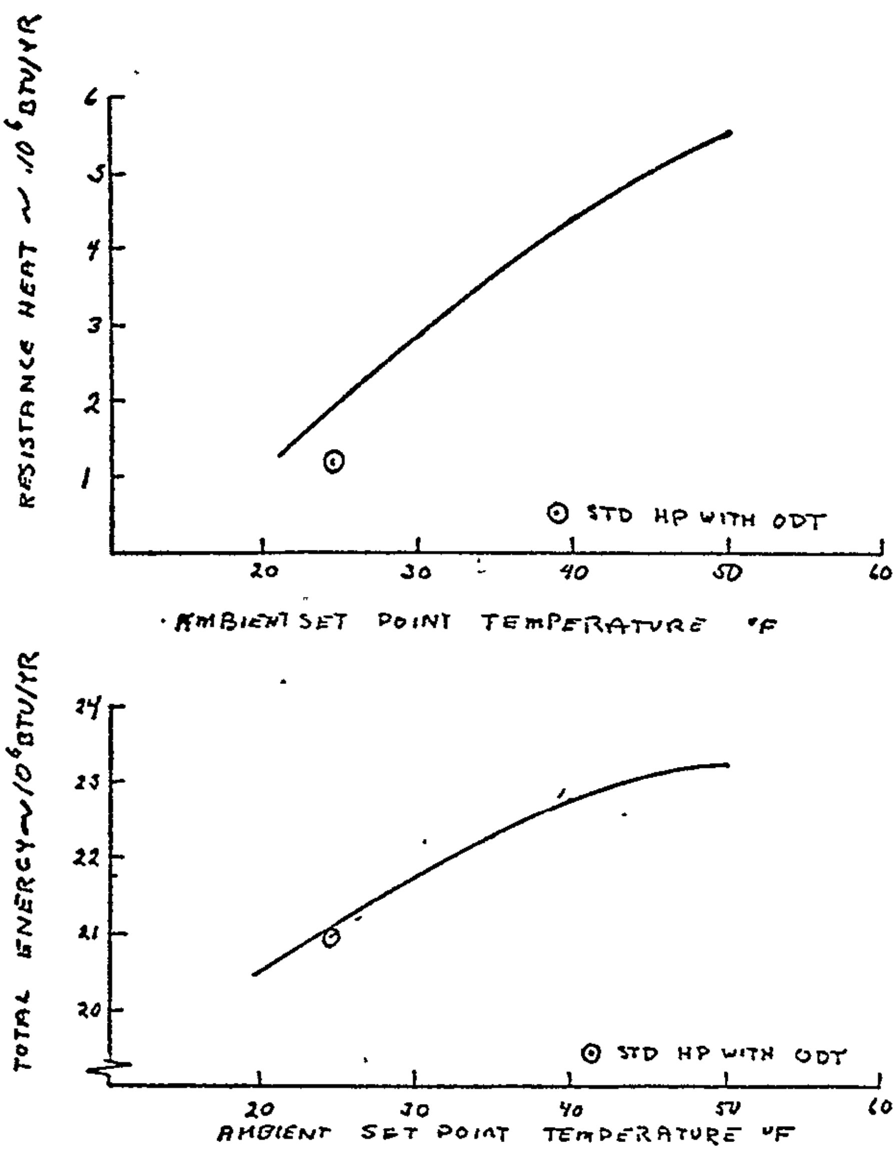

Figure 2.2-2 Solar - Heat Pump Performance
Power Requirements
Washington, DC Climate

FORT WORTH, TEXAS

SINGLE FAMILY RESIDENCE

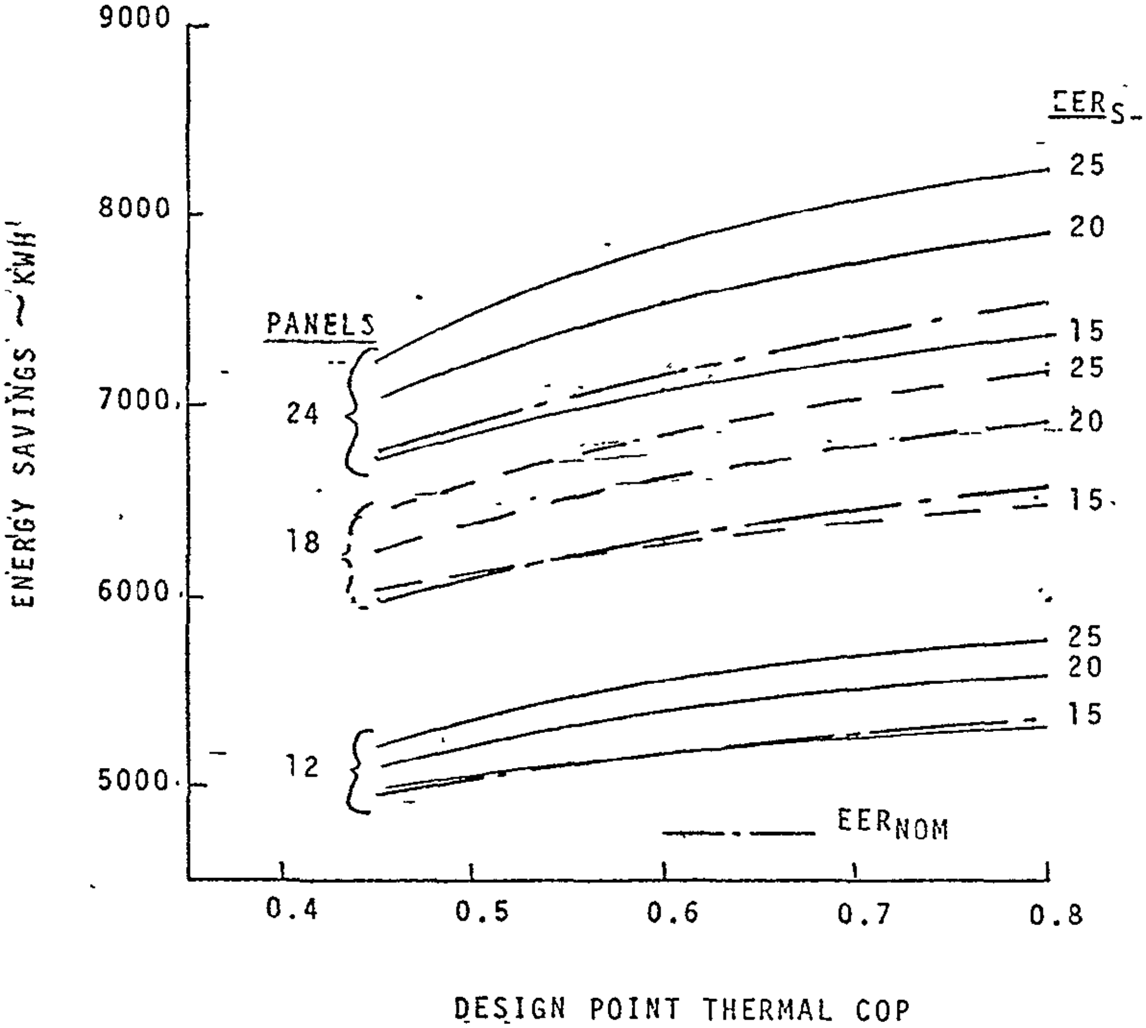

Figure 2.2-3. Solar Heating and Cooling
KWH Savings over a Conventional HP System

FORT WORTH, TEXAS SINGLE FAMILY RESIDENCE

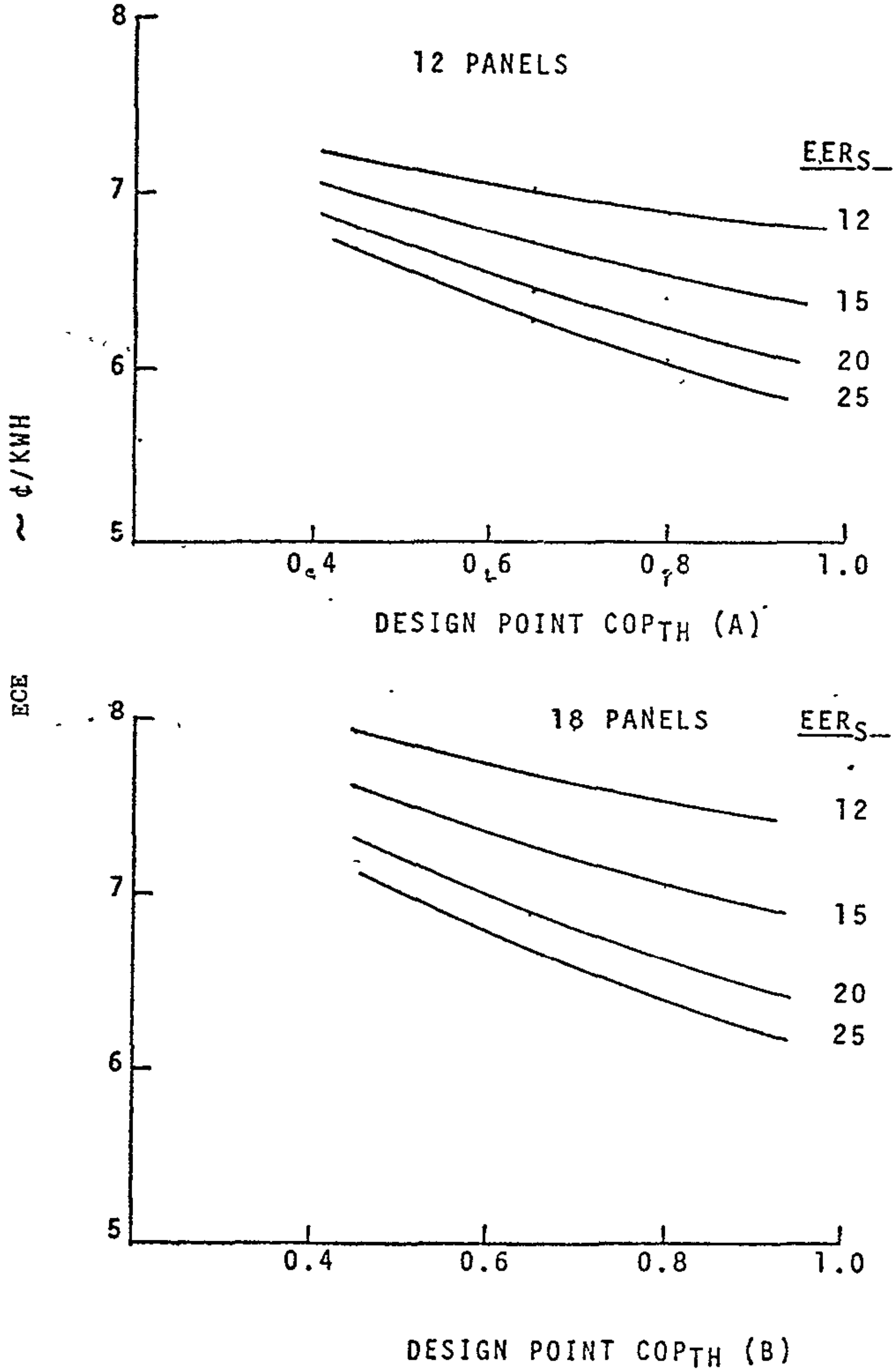

Figure 2.2-4. Solar Heating and Cooling Cost per KWH Saved Over HP System Design Point COP_{TH} Variation

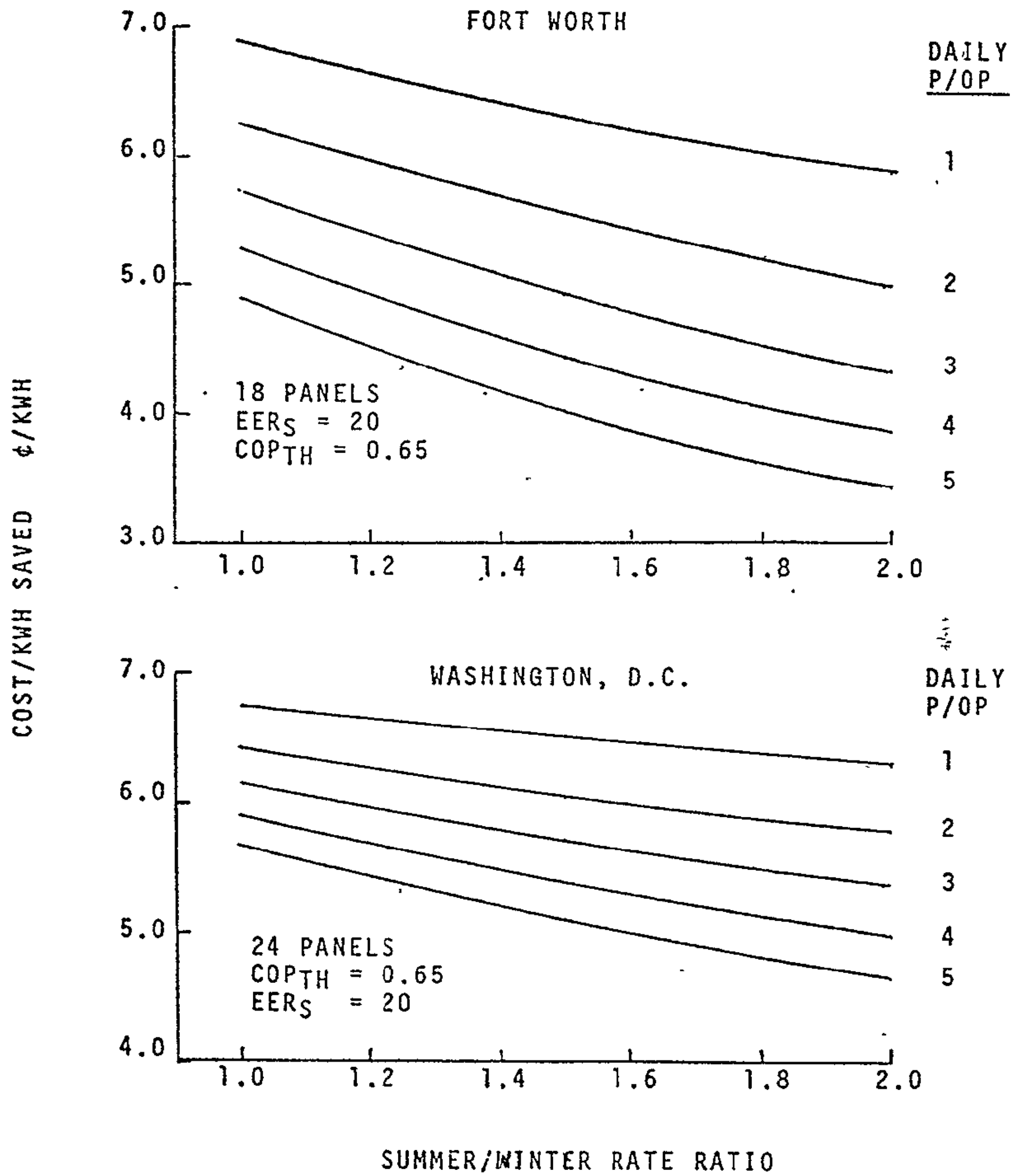

Figure 2.2-5. Solar Heating and Cooling
Cost Per KWH Saved
Winter/Summer Rate Ratio

2.3 SYSTEM DEVELOPMENT (WBS 1.2.2)

2.3.1 HEATING SYSTEMS (WBS 1.2.2.1)

2.3.1.1 Collectors (WBS 1.2.2.1.1)

2.3.1.1.1 Collector Design and Performance Verification

Four new performance verification units were built incorporating modifications resulting from the glass shroud failure analysis. The most significant design change was the incorporation of a high temperature paint to the inner diameter of the shroud. The paint was found to be one of the most economical and effective methods of the prevention of scratches. Other changes included minor modifications to the serpentine structure and the addition of brackets for holding the serpentine in place during shroud insertion. Design changes were also incorporated in the packaging materials to keep the mating surfaces (fin and shroud ID) as clean as possible until time of actual assembly. These changes included a plastic sleeve over the fins and the encapsulation of each shroud in a sealed polyethylene bag.

The failure analysis of the glass breakage problem raised several questions and pointed out that a technique must be developed to evaluate the input of design and process changes on the shroud fragility. Therefore, a statistical technique was developed to evaluate the effect of present and possibly future design and process features.

The first statistical experiment was designed to evaluate the effects of (a) conditioning (Lehr) the glass, (b) the optical coating and its related processes, (c) the anti-scratch protection, and (d) interactions between the above. The evaluation program consisted of pressure testing to failure of a representative sample of each variable in a completely random sequence. After statistically

analyzing the results, the following conclusions were determined:

1. There is no significant difference between Lehred and un-Lehred shrouds.

2. There is a highly significant difference between painted and unpainted (anti-scratch protection) shrouds.

3. There is no significant difference between replication.

4. There are no significant interactions between the three factors.

As a result of these tests, it was decided to eliminate the need for Lehring the glass and to incorporate the paint as an anti-scratch barrier. Subsequent to the initial experiment, similar experiments have been set up and run to evaluate different types of paints and alternate fin configurations.

The new verification units were then placed on performance testing. One unit was shipped to Desert Sunshine Testing (DST) and two units were placed on test at General Electric. Both tests included the use of painted shrouds - only one of 40 shrouds broke. The performance results of the tests are shown in Figure 2.3-1. The performance results at GE and DST were consistent but were well below anticipated results. Since the Y intercept of the verification units fell within a range consistent with predictions, the primary culprit appeared to be the emmissivity. To date, at least two possible causes have been identified. First, oil has been found to be evident on the coated surfaces, which will raise the effective emmissivity of the coating. Second, the coating on the shrouds has been found to be semi-porous and inconsistent to a greater extent than the control specimens. Therefore, the actual performance of the shroud would be less than anticipated. Both avenues are being pursued at this time to resolve and correct the cause of poor performance.

2.3.1.1.2 Collector Integration

The majority of drawings have been completed for collector integration. A bracket scheme for mounting collectors to a flat roof has been developed The only other

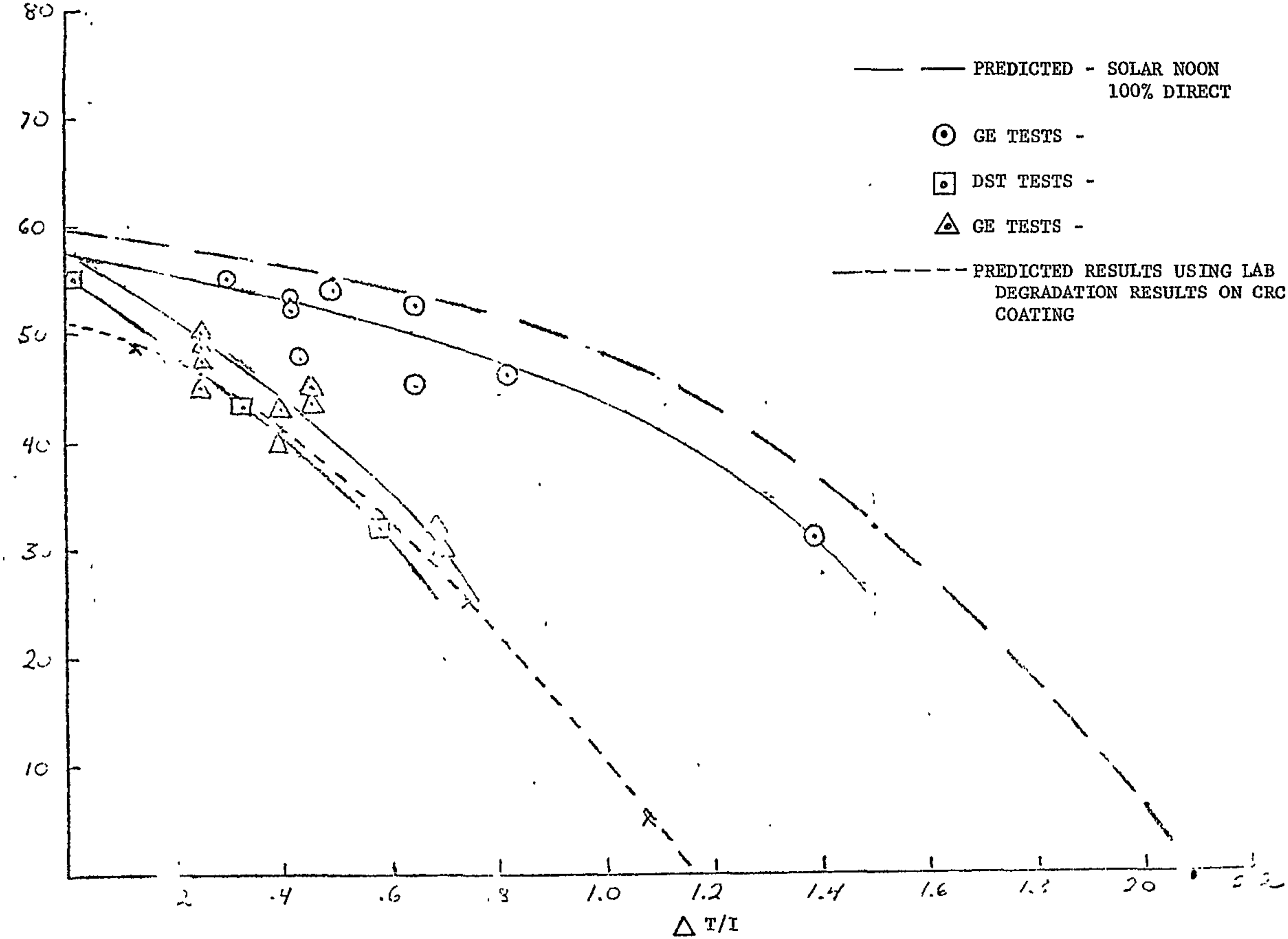

Figure 2.3-1. Verification Collector Performance

activities in this area have included drawing cleanup and revision as experience with the manufacture of parts dictate.

2.3.1.1.3 Primary Heat Dump

A heat dump system has been designed for a 300 collector system. It consists of a 48" diameter by 36" high stainless steel clad tank containing a copper coil, vent, automatic water supply and low level indicator. The design is based on boiling off water as steam for primary loop temperature control. The system appears very attractive and a smaller revision for a 24 collector module is being considered as an alternative to the air cooled finned heat dump.

2.3.1.2 Energy Storage (WBS 1.2.2.1.2)

The Thermal Energy Storage Tank Assemblies for the Milwaukee and Spokane sites were defined and procurement of the long lead items was initiated.

2.3.1.3 Space Heating and Cooling (WBS 1.2.2.1.3)

No significant activity during the reporting period.

2.3.1.4 Auxiliary Energy Systems (WBS 1.2.2.1.4)

Specification No. 261A2884, Boiler, was updated to reflect vendor comments.

2.3.1.5 Hot Water Subsystem (WBS 1.2.2.1.5)

For the Milwaukee and Spokane sites, which have large DHW usage, an external, rather than in-tank units were selected. These units will be procured to the same specification as for HX-1.

2.3.1.6 Energy Transport Subsystem (WBS 1.2.2.1.6)

Effort on the EMM fabrication is continuing.

2.3.1.7 Controls Subsystem (WBS 1.2.2.1.7)

2.3.1.7.1 System Design

Two new system designs have been developed for the HCOMM sites at Milwaukee and Spokane. Major differences between these sites and the original building block concept for Heating Commercial systems are the addition in both designs of a flow switch in the domestic hot water loop and an additional pump in the Spokane system to heat swimming pool water.

The flow switch operates whenever hot water is drawn from the domestic hot water tank. The switch operates the storage loop pump P2 (see Figure 2.3-2) which transfers collected or stored energy from the TES tank to the cold water make-up line through heat exchanger HX- 2 . In the Spokane design, in addition to the flow switch control, a separate distribution loop has been added for swimming pool heating. A manual pool heating switch starts pump P4 (see Figure 2.3-3) provided thermal switches CT5 and CT6 are closed. CT5 sets a minimum TES operation temperature for pool heating. CT6 senses outdoor ambient temperature and inhibits the solar pool heating mode when temperatures fall below 55°F.

2.3.1.7.2 Component Development

2.3.1.7.2.1 Sensors. The first four solar integrator units have been received from Zia and are presently under test and review. Zia has not completed its qualification testing of the units at this time.

2.3.1.7.2.2 System Controls. The system controls package for Milwaukee and Spokane will be fabricated by an HVAC-type controls supplier (Honeywell, Barber-Colman, etc.). A specification for the controls package for Milwaukee has been written; a similar specification is underway for Spokane.

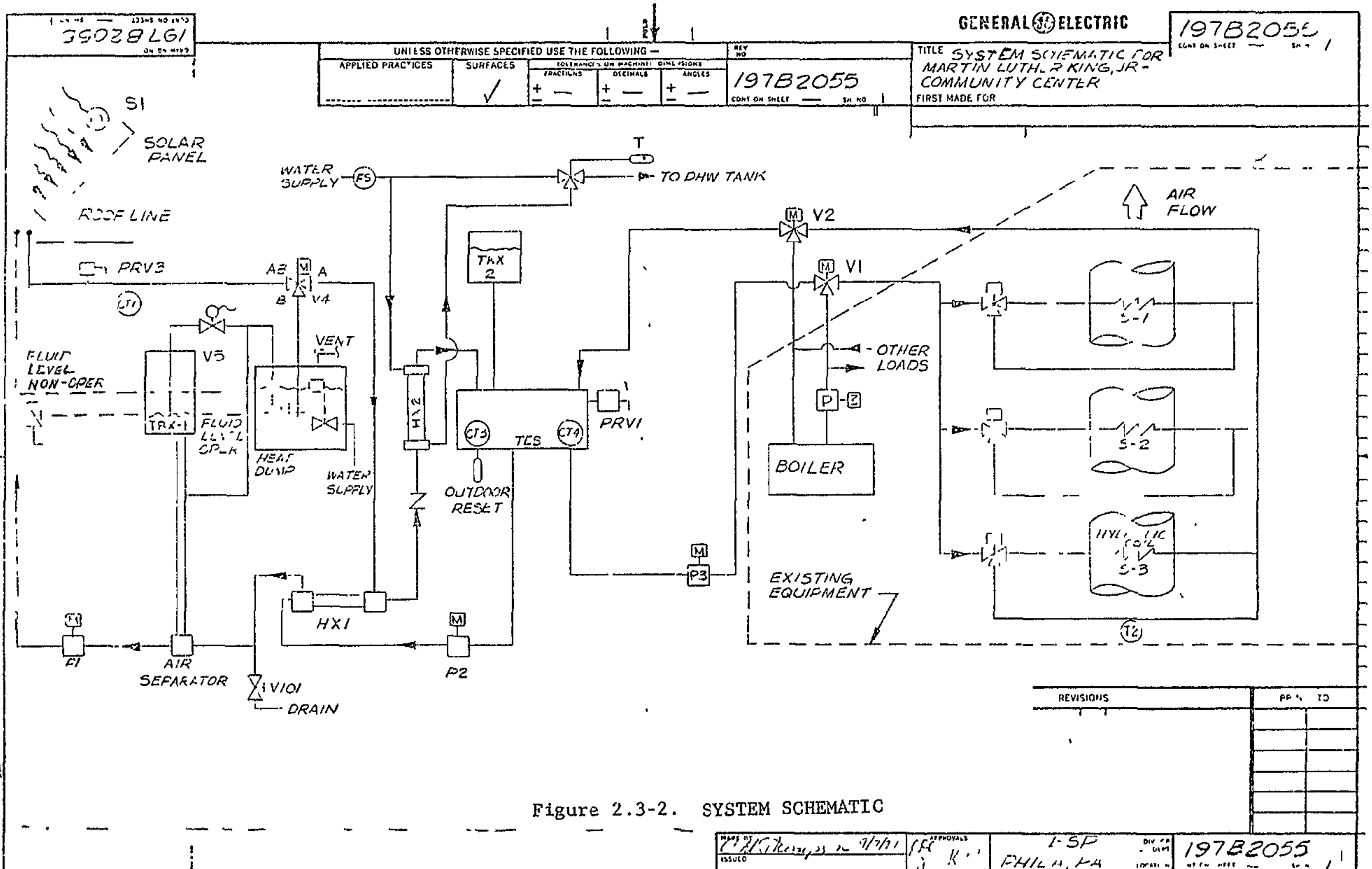

Figure 2.3-2. SYSTEM SCHEMATIC

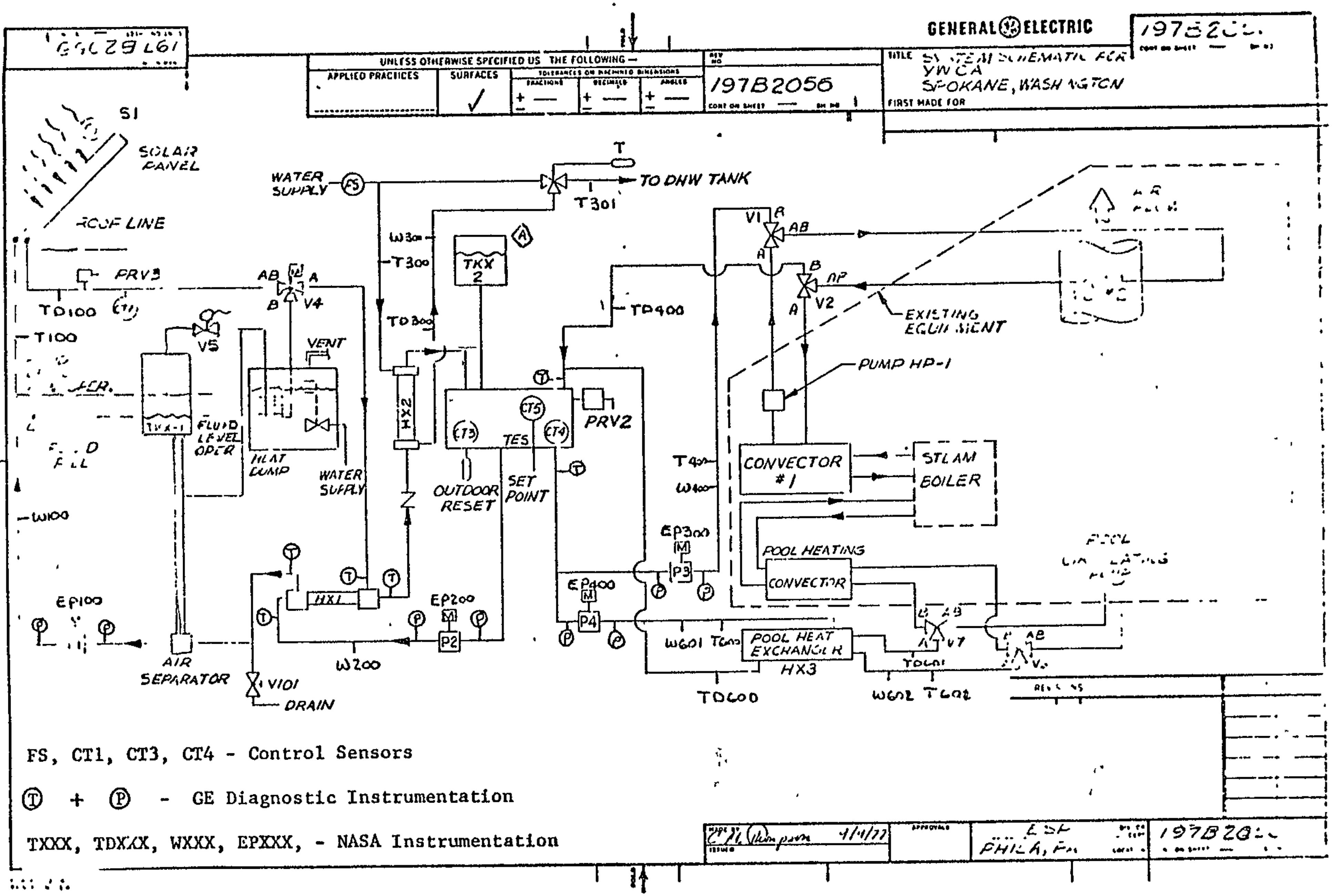

Figure 2.3-3
SYSTEM SCHEMATIC
For YWCA Spokane, Washington

2.3.1.8 Electrical Subsystem

Drawing 132D6029 shows the Control/Electrical drawing for the Milwaukee site, was provided with the PDR data package. A similar drawing for Spokane is currently nearing completion.

2.3.1.9 System Integration (WBS 1.2.2.1.10)

The system integration activities were concentrated toward the detailed definition of the operational test sites. The results of these activities are included in Section 4.1 of this document.

2.3.2 HEATING AND COOLING SYSTEMS (WBS 1.2.2.2)

2.3.2.1 Collector Subsystem (TC-101) (WBS 1.2.2.2.1)

The usage of the high temperature Rankine air conditioner requires a re-evaluation of the TC-100 collector characteristics to ascertain the effects of higher temperature operating conditions. The approach to increasing the collection efficiency at elevated temperatures is to increase the collector concentration ratio with a cusp-shaped reflector. This new collector configuration will be designated as Model TC-101.

The TC-101 collector was modeled and coded into the GE solar simulation code. Utilizing the single family Fort Worth house to provide typical heating and cooling loads, various concentration ratios were simulated,

to define their relative performance characteristics. Decreased energy collection with increased concentration ratio results from a decrease in the number of shrouds per square foot of projected surface area and a decreased field of view of each shroud. The performance of the TC-101 collector exceeds the TC-100 collector up to a concentration ratio of 1.33.

A constraint placed on the TC-101 collector is that the external dimensions of the collector panel must be the same as the current TC-100 panel. As such, only specific concentration ratios associated with integral numbers of shrouds are considered.

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The proposed system will therefore consist of 8 shrouds per panel.

The decision to increase the concentration ratio for higher temperature performance requires the selection of high quality reflective materials with greater stability due to the fact that the average number of reflections has increased. A comprehensive review of existing reflector surfaces is in progress, including the following

materials:

Alzak
Coilzak
Scotchkal 5400
Scotchkal FEK-244
Kingslux
Alglas

Table 2.3-3 shows the selection of preferred material for various weighting factors based on published data. Inhouse testing is presently underway to verify the reported data.

TABLE 2.3-1

Obtainable Concentration Ratios with TC-101 Collector Panel

Number of shrouds per panel	Concentration Ratio
6	1.44
7	1.24
8	1.085
9	0.97

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TABLE 2.3-3. REFLECTOR RATING BASED ON PUBLISHED DATA

Major Reflector Material Selection Criteria

	ALGLAS	KING-LUX	SCOTHKAL	ALZAK	COILZAK
• Spectral Reflectance			X		
• Salt-Fog	X				
• Formability	X		X	X	
• Availability	X				
• Cost	X				
• Repeatability	X				
• Corrosion Resistance	X				
• Self-Cleaning	X				
• Abrasion Resistance		X		X	X
• Manufacture Ease	X	X		X	X

2.3.2.2 thru 2.3.2.6 Ancillary Components for the Heating & Cooling System

Since the November 1976 Preliminary Design Review, a larger data base exists for the ancillary system components. Functional specifications have been prepared for all the major hardware elements; these specifications have been reviewed with major suppliers, revised as required and have been used to procure hardware for the heating only systems.

For the new, higher temperature heating and cooling systems, the specifications will be revised. There does not appear to be any major problems with new requirements.

In the area of pumps, both of the primary pump sources, Taco and Grundfos, indicate that their pumps will be able to meet the new pressure and temperature levels.

Similar responses were obtained from Heat Exchanger manufacturer, Durham-Bush and the tank manufacturer, Wood Industrial Products Co. For the tanks, the only change will be that the ASME working pressure rating will be raised. New pressure relief valves in both the collector loop and the storage loop, uprated to meet the new working pressure levels, will be required.

It is, therefore, concluded that there will not be any major affect on the system ancillary components as a result of the higher rated temperature and pressure levels.

2.3.2.7 Controls Subsystem

2.3.2.7.1 System Design

Few changes have been made in the Heating and Cooling System Controls in this time period. All of the system controls are being reassessed as to the impact of the S/EDHP change to a Hermetic Rankine Unit.

2.3.2.7.1.1 Single Family Heating and Cooling. The only design change in this area is the utilization of a 3 stage heating, 3 stage cooling thermostat. Table 2.3-4 shows the previous heating and cooling staging versus the new system using the 3 stage unit. There is still a 15 minute lockout of electric cooling when solar cooling is available.

2.3.2.7.1.2 Commercial Heating and Cooling. A change in the backup heating method has changed the controls logic. When solar energy stored in the TES tank is available (CT3 > 120^{o}F), a hydronic distribution loop supplies the space heating load to all of the zones. When the tank temperature is low, the heat pump (S/EDHP) is used with an auxiliary backup. This replaces a previous design which used a boiler in the hydronic loop as an auxiliary energy backup.

2.3.2.7.2 Sensors

The last quarterly report described a new sensor development termed an Analog Temperature Switch which provided three temperature switch points from one nickel RTD. With the change to the Hermetic Rankine Engine, the release of a request for quote on this unit has been delayed, awaiting the new higher temperature set points.

Table 2.3-4 Heating and Cooling Thermostat Staging

	PREVIOUS DESIGN		NEW DESIGN	
TES TEMP.	> 127°F	< 120°F	> 127°F	< 120°F
HEATING STAGES				
1st	Solar Heat	Heat Pump	Solar Heat	Heat Pump
2nd	Heat Pump and Auxiliary	Heat Pump and Auxiliary	Heat Pump	Heat Pump
3rd	-----	------	Auxiliary	Auxiliary
TES TEMP.	> 205°F	< 195°F	> 230°F	< 225°F
COOLING STAGES				
1st	Solar Cooling	Electric Cooling	SWITCHOVER VALVE	
2nd	Electric Cooling (after 15 minutes)	Electric Cooling	Solar Cooling	Electric Cooling
3rd	------	------	Electric Cooling (after 15 minutes)	Electric Cooling

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2.3.2.8 Electrical Subsystem

The Heating and Cooling Control/Electrical diagrams, which define the electrical services and interconnections for the 15 building blocks, have been completed.

2.3.2.9 System Integration (WBS 1.2.2.2.10)

No significant activity this period.

2.3.2.10 <u>Cooling Subsystems (WBS 1.2.2.2.11)</u>

The following presents the status of the cooling subsystems development effort. Early in this report period, a major cooling subsystems development redirection occurred. The redirected cooling subsystems include 3 ton and 10 ton capacity split system solar/electric driven heat pumps and their associated equipment. The key design redirection included a conversion from water cooled to air cooled condensing equipment, the conversion of the 10 ton capacity design from a single packaged cooling unit to a split system heat pump, the use of hermetically sealed expander/compressor/motor assemblies, the use of higher Rankine cycle operating temperatures, and the selection of higher performance potential Rankine and refrigerant cycle fluids. Model I expander development activities (designs prior to redirection) continued through this report period with the emphasis on performance evaluation of materials and thermal and mechanical efficiencies.

2.3.2.10.1 Subsystem Analysis

Initial studies were conducted to identify and screen the potential working fluids for both the Rankine and refrigeration cycles. These studies indicated that R-113, R-114, R-133a and FC88 were viable candidates for the Rankine cycle with R-114, R-133a and R-22 for the refrigerant cycle. In order to select an optimum system from these candidates, a detailed analysis was conducted on each fluid. This analysis involved the generation of component operating models for the heat exchangers, single and dual stage rotary vane expanders and rotary vane compressors. These models, in conjunction with a thermodynamic cycle computer program, were used to predict the operating characteristics and performance levels of a variety of single and dual expansion, single and dual fluid systems. Figure 2.3-7 presents a summary of this analysis, showing the predicted Rankine cycle efficiency as a function of expander inlet pressure for the candidate fluids and single and dual stage expanders. Also included is the overall thermal COP (i.e., cooling out/energy

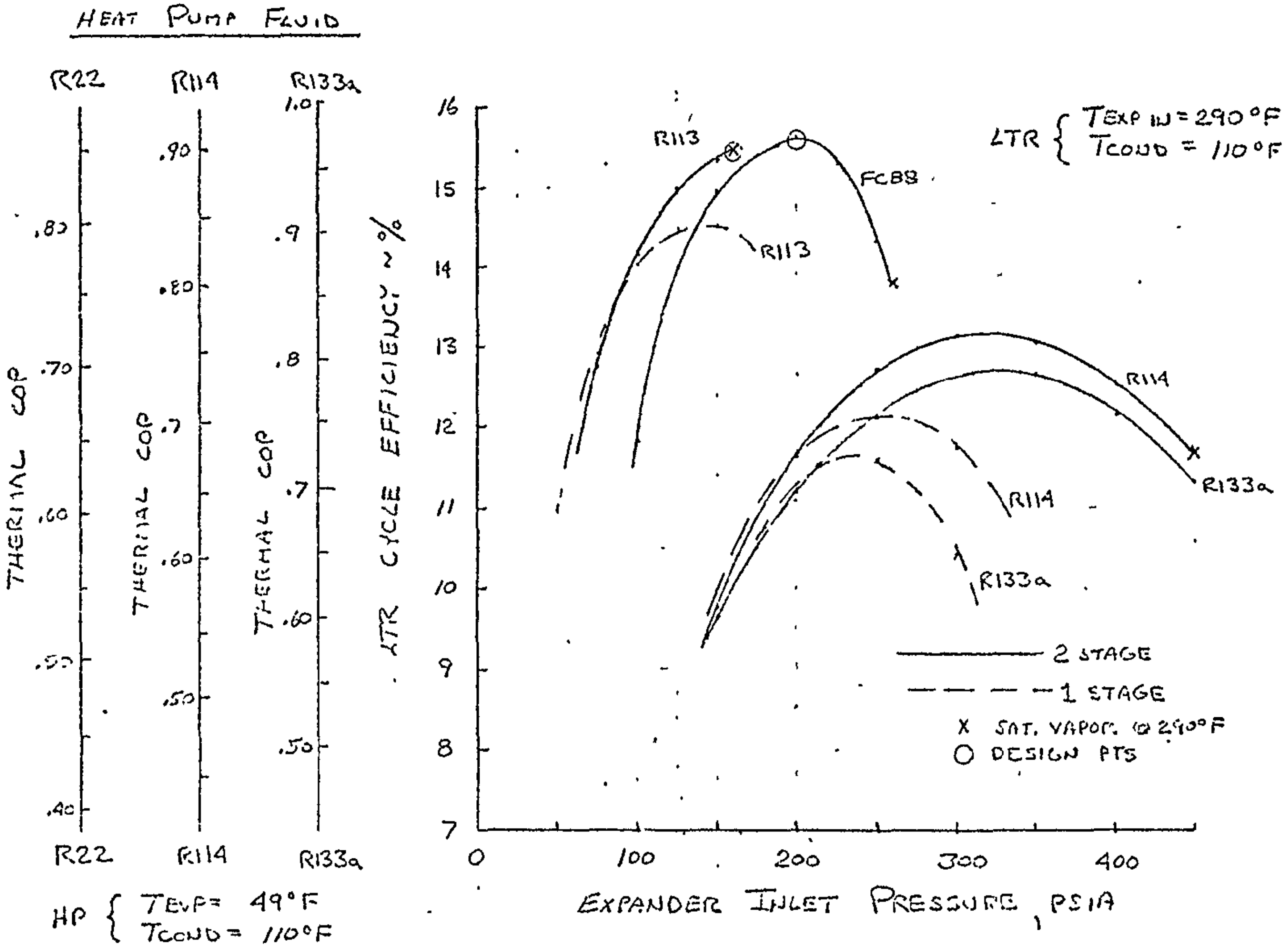

Figure 2.3-7 Preliminary 3-Ton Cooling Performance

into the vapor generator) for the candidate refrigerant cycle fluids.

As a result of the detailed component and cycle analysis, a preliminary design point was selected for an FC88, two stage Rankine cycle coupled to a R-114 refrigerant cycle. FC88 was chosen for its high level of fluid stability and potential for performance improvements with higher collector temperatures R-114 was chosen as the heat pump fluid due to its high performance potential and availability over R-133a. Figure 2.3-8 presents the 3 ton cooling mode preliminary design point cycle diagram and predicted performance.

2.3.2.10.2 HRE Heat Pump

An acronym has been formed to designate the evolution of the S/EDHP. The 3 ton capacity S/EDHP is designated HRE-30 (<u>H</u>ermetic <u>R</u>ankine <u>E</u>lectric). <u>3</u> indicates the capacity in tons and <u>0</u> indicates breadboard type hardware. The <u>0</u> would become <u>1</u> for qualification type hardware. The 10 ton capacity S/EDHP is designated HRE-100, where <u>10</u> indicates capacity in tons and <u>0</u> breadboard type hardware. A number of alternate configurations for the subsystem have been evaluated. The preliminary configuration selection is shown in Figure 2.3-9.

2.3.2.10.2.1 <u>Expander (Model I)</u>. Performance evaluation of efficiency and material selections continued through this report period. A 200 hour endurance test was successfully completed. A peak efficiency of 68% was measured during this test. Materials evaluated included the following:

Rotor - 410 Stainless Steel

Vanes - ALF-10Q TiC coated

End Plates - Ni Resist/Cr_2O_3 coated

Stator - Nitrided Nitralloy

Measurements of wear before and after test indicated no wear on the rotor, end plates, and vanes. A slight amount of wear was measured on the stator. Stator

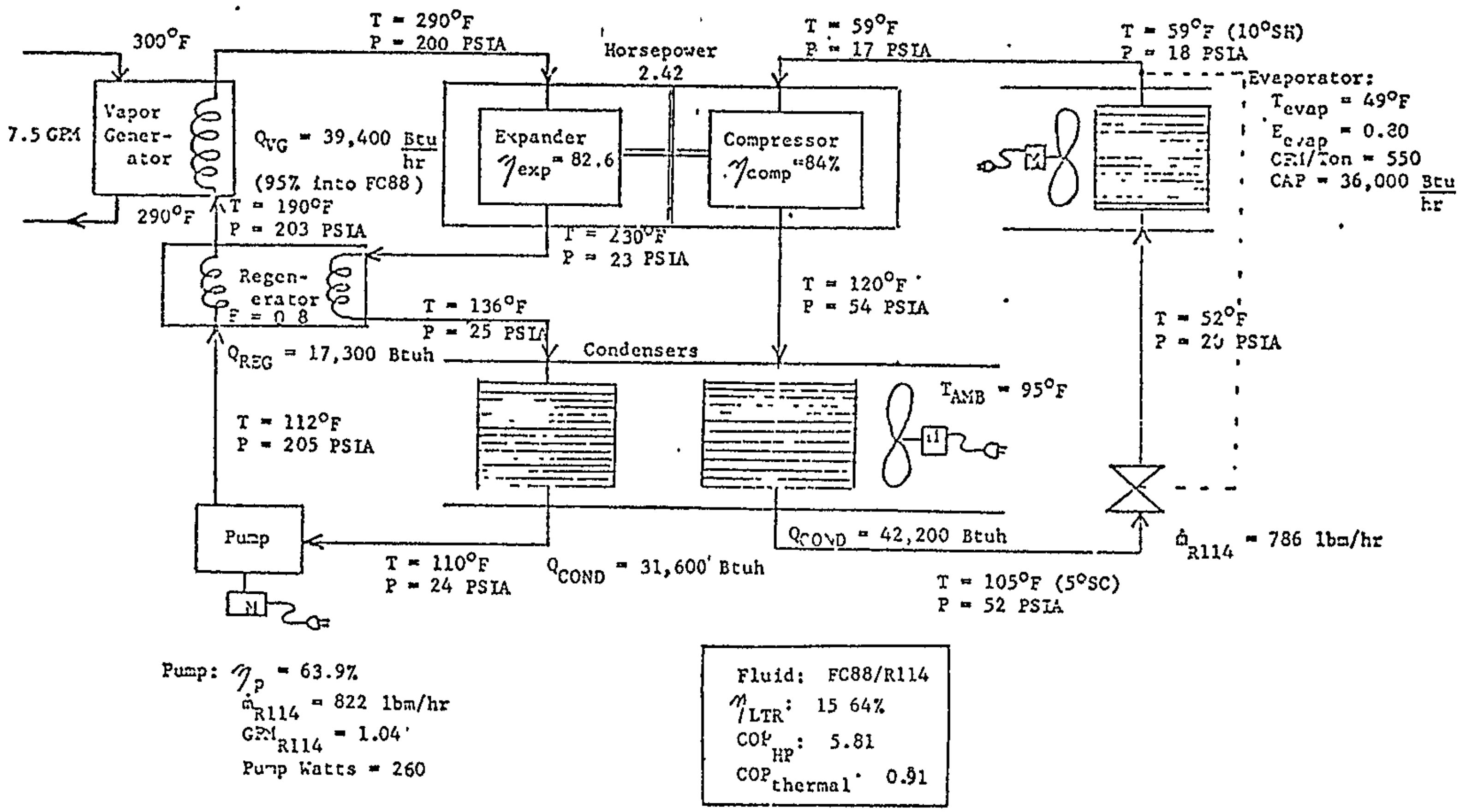

Figure 2.3-8 Two Fluid Preliminary Design Point
3-Ton Cooling Mode

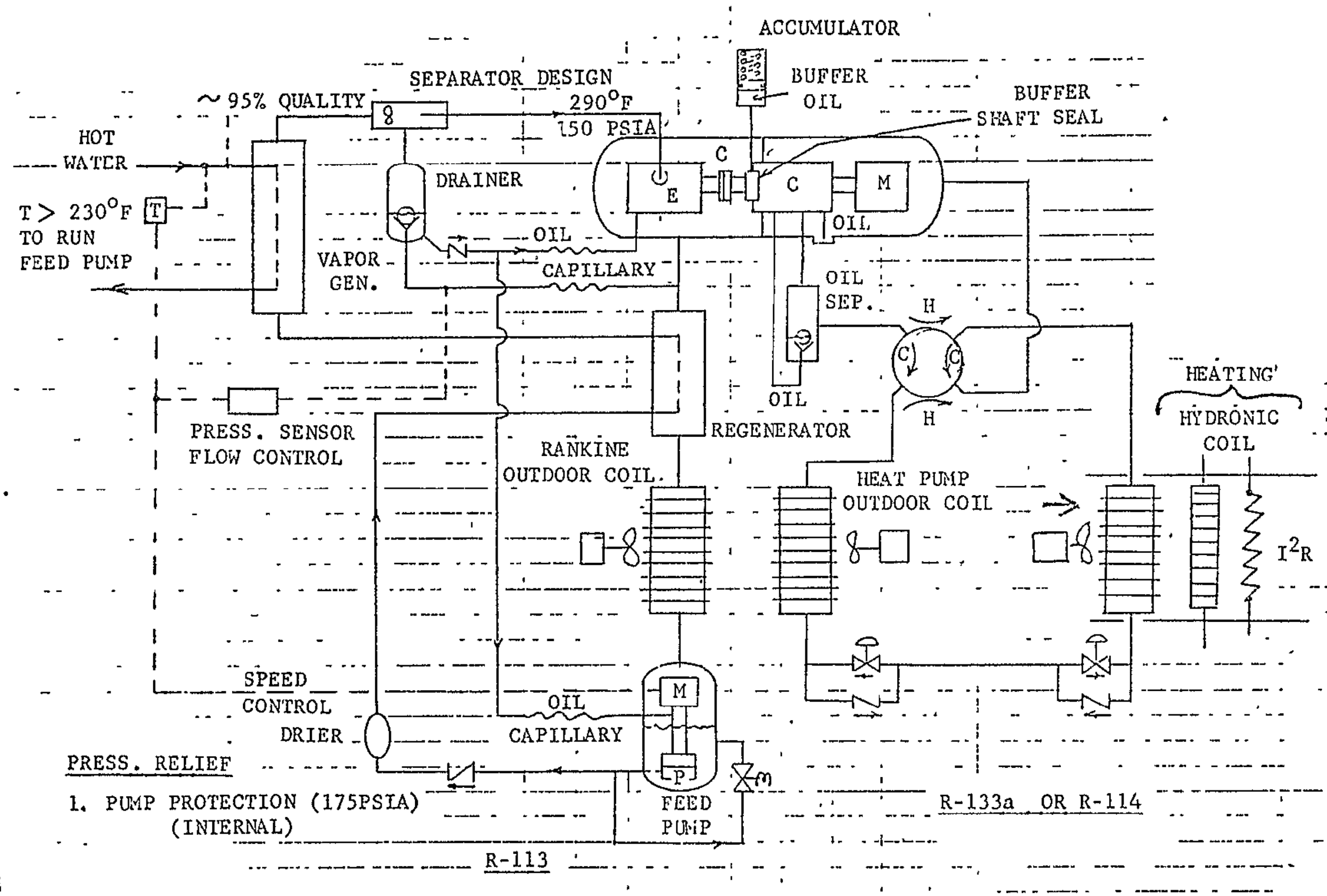

Figure 2.3-9 Preliminary HRE Heat Pump Configuration

surface hardness was increased on subsequent stators with the expected improvement measured on the wear surface. Chipping was evidenced on several vane edges. Preliminary indications are that this particular set of vanes was machined on the edges where chipping occurred subsequent to the vapor deposition process, thereby exposing a base material interface. The seal assembly performed satisfactorily through the duration of the test. Several expander design modifications were also identified as having potential to improve efficiency, reliability and cost. These include the use of a smaller diameter rotor shaft, thicker vanes, and alternate vane and end plate materials.

2.3.2.10.2.2 Hermetic Expander/Compressor/Motor Assembly. A preliminary hermetic expander/compressor/motor assembly concept is shown in Figure 2.3-10. An integrated motor rotor-compressor rotor is used. A clutch is provided between the expander and compressor to decouple the expander during electric drive operation. This approach eliminates the effect of high drag losses during expander free-wheeling and allows simplification of the expander vane pressuration and bearing lubrication design during off-cycle operation. Drag losses on the motor side were considered tolerable (less than 1% of full load motor power) during expander drive operation. All components are hard mounted inside the pressure shell. The shell is divided into two compartments: the expander space and the compressor space. An absolute seal is provided between compartments to isolate fluids by the use of a pressurized oil buffer sealing arrangement. The expander space houses the expander and clutch. The expander is a multi-vane rotary type, similar to the designs used prior to the cooling subsystem redirection. It will be operated in the horizontal position. The clutch is in the selection process. Clutch types being investigated include: electromagnetic disc, electromagnetic tooth, magnetic particle, centrifugal, and overrunning. To date, the electromagnetic tooth clutch appears to be the leading candidate. The compressor space houses the compressor and electric motor. The compressor will be a multi-vane rotary type. Bearing and vane lubrication will be

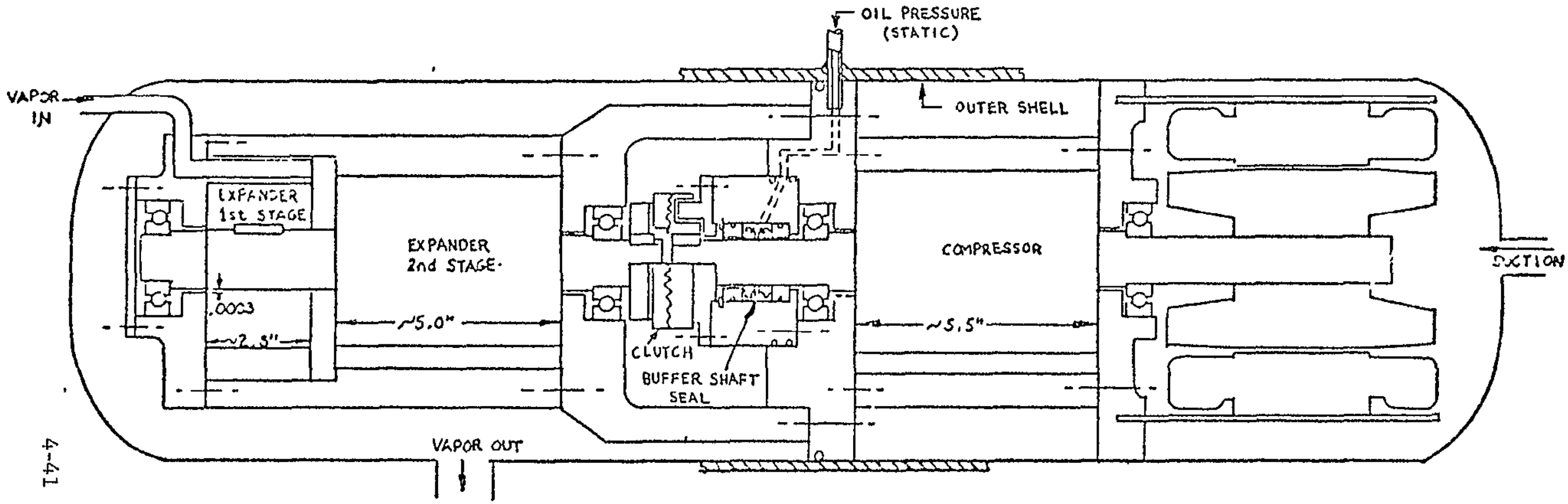

Figure 2.3-10 Preliminary Hermetic Expander/Compressor/Motor Assembly

provided from a refrigerant oil separator. Suction gas will be used to cool the motor windings during electric drive operation. An evaluation of the various separators and hermetic motors has been initiated.

2.3.2.10.2.3 Feed Pump. A preliminary hermetically sealed feed pump assembly concept is shown in Figure 2.3-11. A two-stage pumping unit design approach similar to the one described last report period will be utilized. Evaluation of bearings, lubrication techniques, and hermetic motors was initiated.

2.3.2.10.3 Heat Exchangers

There are five prime heat exchangers being evaluated for the cooling subsystem; the Rankine cycle vapor generator, regenerator, and condensor, and the refrigerant cycle indoor and outdoor coils. Vapor generator analyses indicates a shell and tube type heat exchanger is the leading candidate with the Rankine fluid on the tube side and the EG/H_2O on the shell side. The regenerator analysis was initiated to evaluate what type of heat exchanger should be used. The condenser analysis indicates a plate fin configuration would be the best choice. Tube size, spacing, fins per inch, materials, and circuiting trade-off analyses were initiated. The indoor and outdoor refrigerant to air coils will be of the plate fin type for space efficiency and low air side pressure drop.

2.3.2.10.4 Controls

The controls have been separated into three areas: the system interface controls, the Rankine engine controls, and the heat pump refrigerant controls. Some of the functions breadboarded in the Model I effort have application in the redirected design. Test plans are underway to evaluate these specific electronics functions (digital timer, analog temperature circuit, and electrical expansion valve control).

New design efforts have begun for the electronic modulation of single phase A.C. motors. A triac-controlled voltage-slip design is the preferred method for low

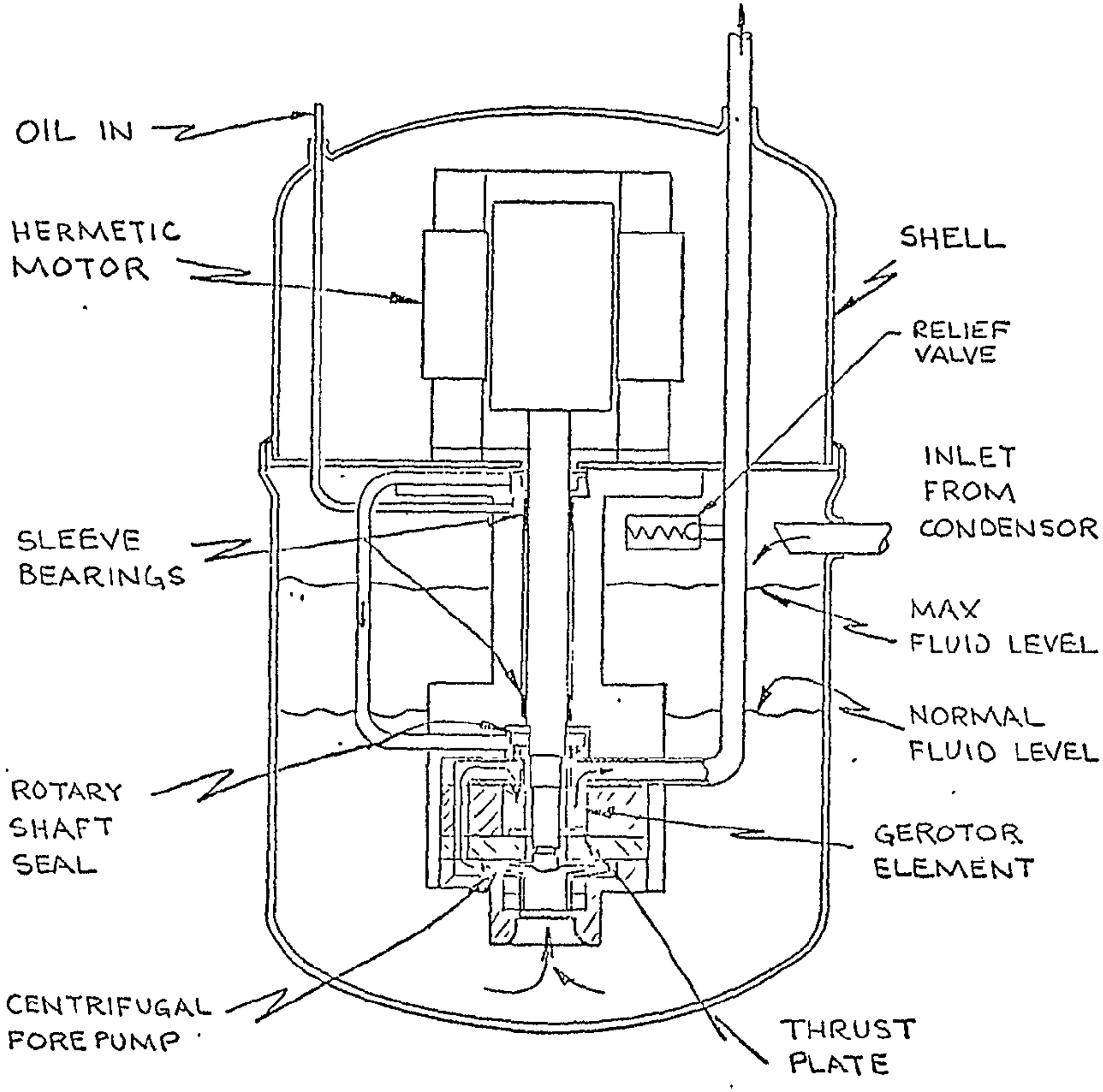

Figure 2.3-11. Preliminary Feed Pump Assembly

cost motor control. A breadboard of the triac system is nearing completion.

A design has been started for the Rankine engine superheat control. Vapor generator water inlet temperature is compared with expander inlet temperature as a measure of superheat. When the delta temperature (ΔT) increases above a certain point, freon flow into the vapor generator is reduced as a control of ΔT. A pressure switch override located at the expander inlet assures that the inlet pressure will not be reduced below a minimum level by the flow control. Superheat is assured by setting a minimum inlet water temperature of 230^{o}F.

2.3.2.10.5 Packaging

Analytical trade-offs involving the optimal sizing and arrangement of subsystem components to achieve performance, parasitic, noise, and cost goals were initiated. The leading outdoor section configuration concept is shown in Figure 2.3-12. the indoor section in Figure 2.3-13. Appearance design work was initiated for the 3 ton capacity HRE heat pump outdoor section. Assembly of the Model I S/EDHP prototype was completed. Calibration of all key components and operational checkout of the LTR using a throttle in lieu of the expander were performed. Test plans were generated for subsystem performance evaluation.

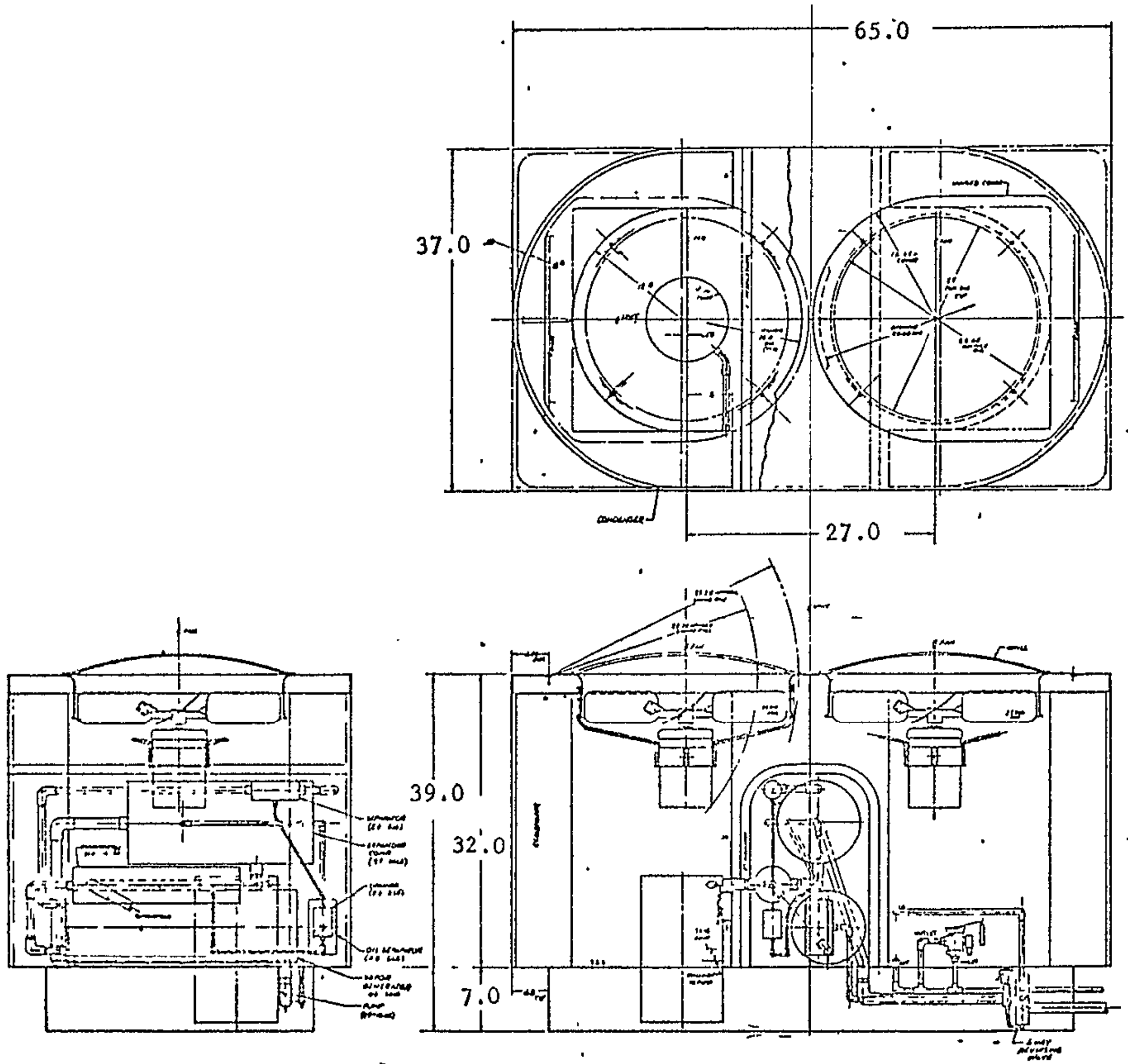

Figure 2.3-12 Preliminary Outdoor Section Concept
3-Ton HTR Heat Pump

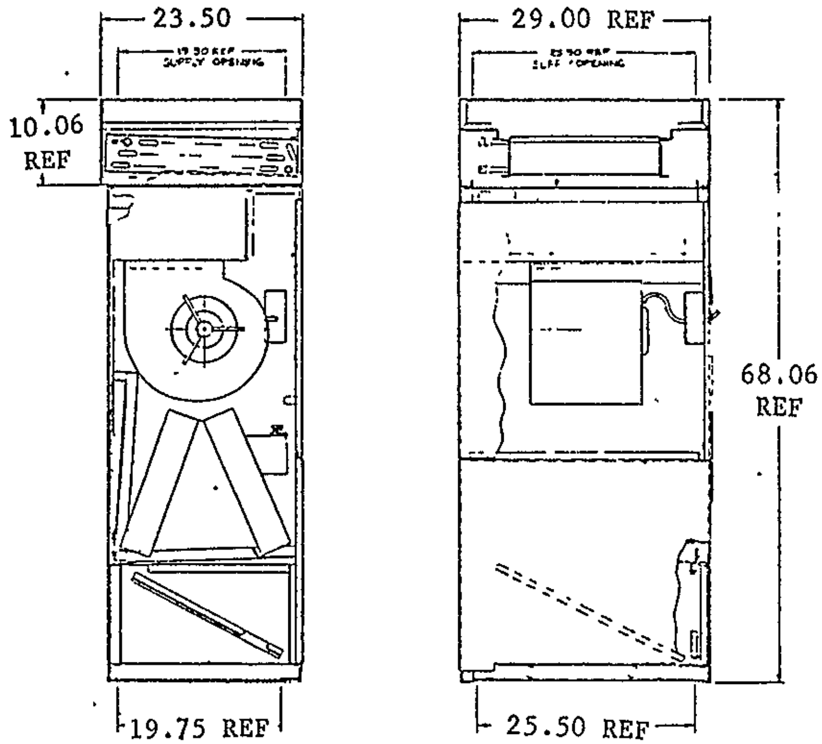

Figure 2.3-13   Preliminary Indoor Section 3-Ton HRE Heat Pump

2.4 Test (WBS 1.2.3)

Testing proceeded at the component, subsystem and system level for 3 ton heating and cooling configurations, for the solar collectors, and for the horizontal TES tank.

2.4.1 Low Temperature Rankine Component Test Loops

The LTR component test loops designated the "A" loops are fully operational having been checked-out and calibrated during this reporting period. The 3A test stand provides for vertical shaft orientation and the 10A test stand is configured for horizontal shaft mounting. During the calibration and initial testing period, several instrumentation changes were made to the test loops, e.g., in the freon loop a rotometer flow meter was added in series with the existing turbine flow meter to provide added data confidence and an excellent visual indication of the freon fluid condition. Other charges included matching and selecting RTD pairs for greater accuracy; also changed delta pressure gauges for water flow measurements using the annubar flow sensors.

2.4.2 HSF Qualification Test

The HSF qualification system was modified to incorporate the horizontal TES tank and pumps. Testing was completed and the test report issued during the reporting period.

2.4.3 Collector Testing

Performance of the verification units was measured in the VF outdoor test facility and stagnation tests were conducted to support the investigation of the thermal coating.

SECTION 3

TASK 1.3 - DELIVERABLE HARDWARE

3.1 NORMAL

Material was accumulated for shipment to the Normal, Illinois site. An area has been set aside to array this material, both for inspection purposes related to the DD 250 and for visual display at FAR. The plan is for shipment early October 1977, immediately after FAR. Shipment will be made via closed van. Glass shrouds will not be available until early November 1977. The TES tank will be shipped with certain fittings and piping pre-assembled to the tank.

3.2 MILWAUKEE

Following the Prototype Design Review, placement of orders began on 9/26/77, for all Milwaukee equipment with the exception of the Lexan covers which are held pending cost information and TC-100 shrouds. The purchase order for theTES tank has been placed with the Wood Co. as an advance order item. Milwaukee delivery is scheduled for late November, 1977.

3.3 SPOKANE

Following the Prototype Design Review, placement of orders for equipment for the Spokane site began 9/26/77. The TC-100 shrouds are not ordered pending resolution of problems. The TES tank was advance ordered as a long lead item. Hardware delivery for the Spokane site is scheduled for shipment early December. The supplier of the TES tank (Wood) is being asked to improve his December, 1977 delivery date to November 1977. If this can be done the tank will be shipped and arrive on site late November.

SECTION 4

TASK 1.4 - OPERATIONAL TEST SITES

4.1 SITE IDENFITICATION

Operational test activities in this period included the identification and inspection of sites selected by NASA/MSFC. Sites that have been investigated are listed in Table 4-1 and those visited during this period are indicated with a dash line. The sites accepted are shown in Table 4-2 along with the dates of acceptance. As a part of the program redirection, GE will search for suitable sites in the Philadelphia area including GE owned facilities for one each residential and commercial heating and cooling systems. The size of the commercial operational test site systems has been reduced to one each 10 ton unit as a part of the redirection.

TABLE 4-1

SITES INSPECTED BY GE

Bldg. Type	General City	Site
HSF	Baltimore	7502 Young St., Ft. Meade, MD.
HCOM	Muscle Shoals	TVA Office at Muscle Shoals, AL.
HMF	Nashville	Airman's Quarters, AEDC, Tullahoma, TN.
HSF	Peoria	Chanute Air Force Base
HSF	Peoria	MHA, Champaign, ILL.
HSF	Peoria	ISU House, Normal, ILL.
HMF	Schenectady	MHA, Schenectady, NY
HMF	Schenectady	VA Hospital Staff Housing, Albany
HMF	Schenectady	Ely Park Housing, Binghamton, NY
HCMF	Chicago	Ft. Sheridan, ILL
HCMF	Chicago	Great Lakes Naval Training Center
HCOM	Madison	Hill Farm State Office Bldg., Madison, WI
HCOM	Milwaukee	Washington Park Senior Citizens Center
HCOM	Milwaukee	Washington Park Community Center
HCOM	Milwaukee	Dr. Martin Luther King Community Center
HCOM	Spokane	YWCA
HCOM	Spokane	East Washington State College
HCOM	Spokane	Community College
HCCOM	Los Angeles	West L.A. Municipal Bldg.
HCCOM	Los Angeles	Dept. of Water & Power #1
HCCOM	Los Angeles	Dept. of Water & Power #2
HCCOM	Los Angeles	Peck Park Rec. Bldg.
HCCOM	Los Angeles	Police Credit Union
HCSF	Dallas	President's Home, Univ. of Texas at Dallas
HCSF	Dallas	President's Home, N. Texas State, Denton, Texas
HCSF	Dallas	Grad Student Housing at SMU

TABLE 4-2

OPERATIONAL TEST SITE STATUS

TYPE	LOCATION	DATE ACCEPTED BY GE	COMMENTS
HSF	Ft. Meade, Md.	Jan 19, 1977	
HSF	Normal, Illinois	Feb. 7, 1977	
HMF	Tullahoma Tenn.	Feb. 7, 1977	Multi-family units dropped from program verbally on April 4 and documented in minutes of April 4 meeting
HCOM	Muscle Shoals, Alabama	Jan 19, 1977	Converted to Heating and Cooling Site on 4/20/77*
HCOM	Milwaukee, Wisconsin	May 23, 1977	
HCOM	Open		
HCSF	Dallas, Texas		Best of Dallas/Ft. Worth sites reviewed. Being reviewed for GE acceptance.
HCSF	Open		
HCCOM	Muscle Shoals, Alabama	April 20, 1977	
HCCOM	Open		

* Design activity was on hold pending this decision.

NOTE: Great Lakes, Illinois was accepted as a HCMF site on Feb 7, 1977. All multi-family sites have been dropped from the program.

4.2 SITE DESIGN

4.2.1 ACTIVITY SUMMARY

Analysis of the Milwaukee, Wisconsin and Spokane, Washington commercial heating only sites was completed during this period and culminated with the Prototype Design Review held September 21, 1977. Comments on the activity of each site follow.

4.2.2 NORMAL, ILLINOIS HSF-2

Design analysis was completed for this site and reported at a design review meeting held last quarter. The architect has completed his work on this project and a bid package has been sent out to contractors in the Normal, Illinois area. A First Article review is planned for the next quarter with system installation and checkout to follow.

4.2.3 MILWAUKEE, WISCONSIN HCOM-1

The selected solar system for the Martin Luther King, Jr. Recreation Center will consist of 300 GE TC-100 solar collector panels. The collected energy will be stored in a 2500 gallon storage tank until needed. This system will supply 10 percent of the space heating load of 1063 MMBTU/YR and 61 percent of the domestic hot water load of 682 MMBTU/Yr. The prototype Design Review was held at G.E. Valley Forge during this reporting period. An engineering firm has been identified for this site and has started the installation design. His work is being held up at the present time, waiting for the site owner to select an architect to perform the structural work needed on the building.

4.2.4 SPOKANE, WASHINGTON HCOM-2

A system consisting of 300 GE TC-100 vacuum tube collector panels has been specified for the Spokane YWCA. A 6750 gallon water storage tank will be utilized to store the collected solar energy. This solar system will provide 22 percent of the annual space load of 1690 MMBTU, and 44 percent of the 1680 MMBTU hot water requirements. The not water requirements include energy required to heat the swimming pool. The prototype design review was held at the G.E. Valley Forge during this reporting period. An Engineering firm has been selected to perform the installation design work and prepare the bid package. He will begin work in the next reporting period on this design.

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